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A SURVEY OF ARCHAEOLOGICAL SAMPLES DATED IN 1984

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Abstract: A survey is given of archaeological samples dated in 1984 at the Nordic Laboratory for Thermoluminescence Dating. A total of 79 samples were dated, 49 of which were burnt stones. All results were corrected for fading as measured for samples stored for four weeks at room temperature. The alpha dose contribution from uranium in the quartz and feldspar grains was included assuming an alpha efficiency factor of 0.1 for quartz and 0.2 for feldspars.

INIS-DESCRIPTORS: AGE ESTIMATION; ARCHAEOLOGICAL SPECIMENS; DENMARK; FINLAND; SWEDEN; THERMOLUMINESCENCE

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CONTENTS

INTRODUCTION

The Nordic Laboratory for Thermoluminescence Dating (TL Dating) was established January 1st, 1983. It is financed by the Nordic Council of Ministers and the Research Councils in the Nordic countries in the form of grants given to customers. The laboratory receives samples for dating from archaeologists and geologists in the Nordic countries. The technique for dating archaeological materials, ceramics, bricks, burnt clay and burnt stones is fairly well established, and the uncertainty of dating is usually within 5-7%. To a large extent, dating of geological sediments is still at the experimental stage.

The dating capacity is around 100 archaeological and 60 geological samples a year. A survey of archaeological samples dated in 1983 is given in Mejdahl (1984). The present report describes TL dating of archaeological samples in 1984. A total of 79 samples were dated (Table 1).

Table 1. Archaeological samples from the Nordic countries dated in 1984 at the Nordic Laboratory for TL dating.

Material	No. of samples	Percent
Ceramics	17	22
Bricks	1	1
Burnt clay	12	15
Burnt stones	49	62
Total	79	100

TL DATING TECHNIQUE

Our dating technique is based on grains of quartz and feldspar greater than 0.1 mm. The minerals are separated by suspension in heavy liquids. Three fractions are obtained: potassium feldspar (~ 12% K), sodium feldspar (~ 5% K) and quartz. The liquids were made up by mixing two organic liquids or by preparing aqueous solutions of a tungsten compound, $3Na_2WO_4.9WO_3.H_2O$. The TL measurements were carried out by means of two automated TL readers.

The TL age (for a feldspar sample) is given by the following equation:

$$A = \frac{AD}{(E + B_S + B_K + D_U)} \qquad (1)$$

where

A is the age since firing
AD is the dose accumulated since firing
E is the annual dose from environmental radiation
B_S is the annual dose from the gross sample
B_K is the internal annual dose from potassium in feldspars
D_U is the annual alpha and beta doses from uranium in feldspars

The methods used for measuring AD, E and B_S are described in Bøtter-Jensen et al. (1983), Bøtter-Jensen and Mejdahl (1983) and Mejdahl (1982, 1983, 1985a,b). Calculation of B_K requires a determination of the potassium content in the feldspar grains and this was done by beta counting using a multicounter system described by Bøtter-Jensen and Mejdahl (1985). The uranium content in the feldspar grains, used for calculating D_U, was determined by delayed neutron counting (Kunzendorf et al., 1980).

It is apparent from eq. (1) that a considerable number of measurements are required to obtain a TL date and this limits the accuracy that can be achieved. A further complicating factor is fading of the latent TL signal in the minerals after irradiation. The effect is seen especially in feldspars but is not totally absent in quartz. Laboratory experiments indicate that the fading is a short-term phenomenon occurring within one month or less after the irradiation.

We have estimated the fading by comparing the TL signals from two sets of samples that were given large doses (20 Gy) on top of their natural doses with a four-week interval and measured immediately after the irradiation of the second set. Results for 85 samples (including 5 quartz samples) are shown in Fig. 1. 46% of the samples faded less than 10% and 94% faded less than 30% in four weeks. The results for potassium feldspar appear to fall into two groups: results greater than 0.9 and results between 0.65 and 0.8.

The fading has been measured for all samples discussed in the following, and the TL ages have been corrected accordingly. In many cases it has been necessary to use heated rather than natural samples, but a comparison has shown that the results are very similar. In a few cases (see e.g. Hellum, page 5) it has been possible to compare TL dates with radiocarbon dates (calibrated), or other age estimates and good agreement is found when fading corrections are applied to the TL ages.

The uranium content in quartz and feldspars are determined routinely for all samples. Values for 242 samples are shown as histograms in Figure 2. It is clear from these values that the contribution from inherent uranium cannot be neglected. The beta dose contribution is included with sufficient accuracy in the beta dose from inherent potassium determined by beta counting. Calculation of the effective alpha dose requires a determination of the alpha efficiency factor or a-value for feldspars. An a-value of 0.2 was measured for three samples by Ann Wintle, Cambridge. This value has been adopted for all feldspar samples

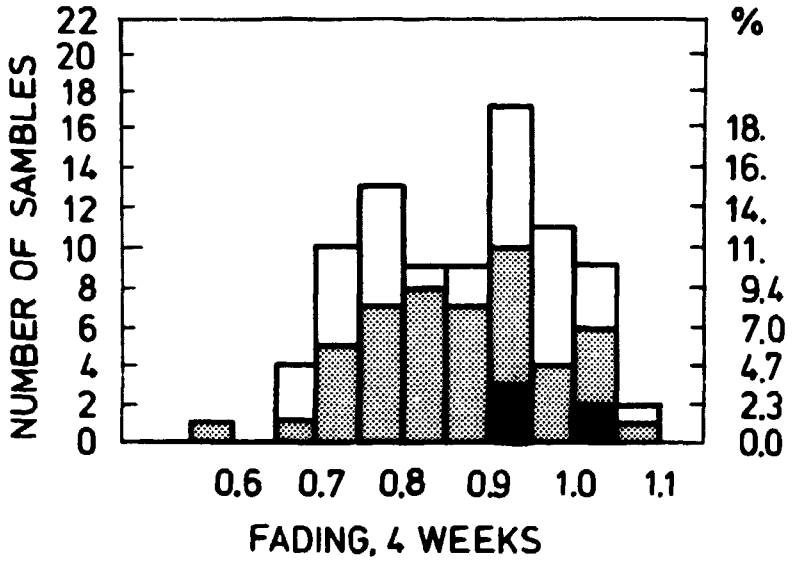

Fig. 1. Fading of TL in quartz and feldspar samples. ■ quartz, ▨ sodium feldspar and □ potassium feldspar. Doses of 20 Gy were added to the natural doses, and the samples were stored at room temperature for four weeks. Total number of samples 85.

in the present study. The a-value for quartz was assumed to be 0.1. The assumption of the same a-value for all samples is clearly inadequate, and alpha sources are now being obtained so that the a-value can be determined for each individual sample.

There might be a small alpha dose contribution from inherent thorium as well, but this has been neglected in the present study. Thorium concentrations for a series of samples are now being measured by neutron activation analysis.

The approach used assumes that the effect of zoning (concentration of alpha radioactivity in low-sensitive areas of the grains) is negligible. However, in a study of alpha activity of quartz grains, Sutton and Zimmerman (1978) observed the occurrence of zoning in quartz grains extracted from granitic rocks. It would be essential, therefore, to ascertain whether zoning is present in quartz and feldspar grains from our samples.

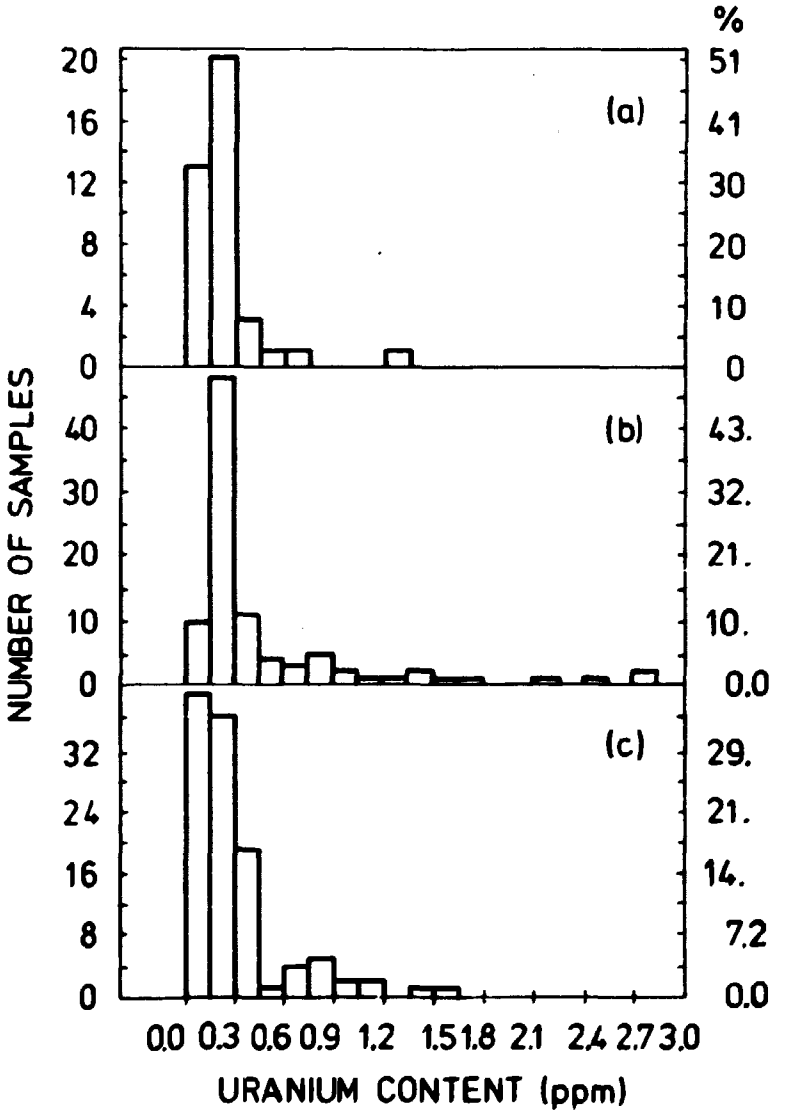

Fig. 2. Uranium content in quartz and feldspar samples. a) quartz, 39 samples, b) sodium feldspar, 93 samples, and c) potassium feldspar, 110 samples.

Tables with annual beta and gamma (including cosmic-ray) doses are given for all samples. The beta doses are infinite-matrix doses usually measured on dry samples for pottery and clay and wet samples for burnt stones. The actual beta doses to the mineral grains used depend on the grain size and the potassium content. The attenuation of the external beta and the beta contribution from inherent potassium increase with grain size as shown in Table 2 calculated from Mejdahl (1979). The TL dating results listed in the following were obtained by taking mean values for different grain sizes of the two feldspar minerals and quartz.

Table 2. Average grain attenuation factors for external beta radiation and annual beta doses from 1% inherent potassium. Calculated from Mejdahl (1979).

Grain size (mm)	Beta attenuation factor	Beta dose rate for 1% K (mGy/a)
0.1 - 0.3	0.893	0.058
0.3 - 0.5	0.818	0.116
0.5 - 0.8	0.737	0.187
0.8 - 1.0	0.662	0.254
1.0 - 2.0	0.529	0.390
2.0 - 4.0	0.334	0.578

TL DATING RESULTS, DENMARK

A total of 33 samples from ten Danish sites were dated in 1984 and these sites are discussed in turn.

1. Solvig, Southern Jutland

Remnants of a fortified estate were excavated in the period 1966-1973 under the direction of Johs. Hertz, now at "Riqsantikvarens arkæoloqiske Sekretariat", Copenhaqen.

The environmental radiation was measured by on-site TL dosimetry in 1973, and samples of burnt clay and bricks were collected for TL datinq. The datinq carried out in 1984 comprised three samples listed in Table 3. Annual beta and gamma doses along with alpha doses from inherent uranium are given in Table 4. The TL dates obtained are presented in Table 5. The localities ØI and ØII (Table 3) were expected to be almost contemporaneous, ØII being perhaps a generation more recent than ØI. The TL results are in good agreement with expected ages, except that ØII appears to be slightly older than ØI. However, within the dating accuracy, the results for ØI and ØII are identical.

Table 3. Samples of burnt clay and bricks from Solviq dated in 1984.

Risø TL no.	Material	Feature	Locality	Expected aqe
R-732803-06	Clay	Burned house	ØI	14th century
R-732809-12	"	Hearth	ØII	"
R-742804-06	Brick	Wall		16th century

Table 4. Annual alpha (inherent U), beta and gamma doses for samples from Solvig.

Risø TL no.	Beta (mGy/a)	Gamma (mGy/a)	Alpha (mGy/a)
R-732803-06	2.35	0.63	0.12
R-732809-12	1.71	0.56	0.12
R-742804-06	2.31	0.74	0.40

Note: Doses are given in Gray (Gy) or milliGray mGy).

Table 5. TL dates obtained for burnt clay and bricks from Solvig.

Risø TL no.	Material	Locality	TL date	Fadings in 4 weeks
R-732803-06	Clay	ØI	1390 AD ± 50 a	0.96
R-732809-12	"	ØII	1330 AD ± 50 a	0.98
R-742804-06	Brick		1570 AD ± 50 a	0.91

Note: The uncertainty stated is the total uncertainty (1σ) including systematic errors.

2. Hellum, Himmerland

A special type of pottery kiln built around a big stone (Fig. 3) was excavated in 1983 by Jan Kock, Ålborg Historical Museum (Kock 1984). The kiln was filled with wasters from the last

fired and remains of about 70 vessels could be distinguished. Based on the ceramics, the kiln was estimated to date from about 1200 AD.

Fig. 3. Medieval pottery kiln found at Hellum, Himmerland, Denmark. A TL date of AD 1210 ± 50 a was obtained from wasters found in the kiln. From Kock (1984). By courtesy of Jan Kock and SKALK.

The TL dating was based on two ceramic samples, each weighing about 200 g. The results are given in Table 6. The environmental radiation, measured with a scintillation counter, was 0.50 mGy/a. The alpha dose contribution from inherent uranium in the feldspar grains was about 0.2 mGy/a. The TL dates are in good agreement with the expected age of the kiln.

Table 6. TL dates of potsherds from a pottery kiln found at Hellum.

Risø TL no.	Arch. no.	TL date	Fading, 4 weeks
R-832901	1399	1210 AD ± 50 a	0.87
R-832902	1399	1210 AD ± 50 a	0.87

Three samples of charcoal from the kiln were dated by radiocarbon (K-4220, K-4221 and K-4222). Calibrated according to Stuiver (1982) the dates yielded a range 1030-1150 AD in which each value has the same probability. Considering that the radiocarbon dates refer to the mean age of formation of the annual rings in the samples and therefore must be earlier than the application in the kiln, the results of the two methods are in satisfactory agreement.

3. Albani Torv, Odense

An excavation of the old Albani Church in Odense was carried out in 1983 under the direction of Eskil Arentoft, Møntergården, Odense (Arentoft et al. 1985; Arentoft 1985). Beneath the remains of two wooden churches a pit for church bell casting was found. The pit had been disturbed by later activities and only a small part was intact. The pit contained parts of a mould of burnt clay for a fairly small bell. Albani Church is well-known from history as the place where King Canute the Holy was murdered in 1986. The traces of bell casting found under the churches are expected to be among the oldest in the country.

TL dating was made on lumps of burnt clay from the mould. Unfortunately, the environmental radiation was not measured during the excavation, and an attempt to measure the radiation after-

wards by means of TL dosimeters enclosed in a steel tube was unsuccessful because it was not possible to reach down to layers similar to those that had surrounded the casting pit. The layers were rather sandy, and a gamma dose rate of 0.60 ± 0.10 mGy/a was assumed from earlier experience with similar layers. The beta dose rate was 2.20 mGy/a and the alpha dose contribution from inherent uranium was about 0.10 mGy/a. Three samples were dated, and the results are given in Table 7. The TL dates are slightly more recent than expected. The imprecise assessment of the environmental radiation contributes significantly to the uncertainty of the TL dates, Lowering the assessment to 0.50 mGy/a (not unlikely) would increase the mean TL age to about 1000 AD.

Table 7. TL dates for burnt clay from the mould for church bell casting found beneath Albani Church, Odense.

Risø TL no.	Arch. No.	TL age(a)	Fading, 4 weeks
R-840801	AT83	998	0.95
R-840802	"	990	0.95
R-850301	"	883	0.95
Mean TL date		1030 AD ± 60 a	

4. Bellingegård near Køge

An Iron Age village excavated in 1983 by Køge Museum under the direction of Svend Åge Tornbjerg. The village comprised at least seven houses or farms each of which had been rebuilt 2-5 times. The expected age was Younger Roman to Older Germanic Iron Age, i.e. AD 200-600.

The environmental radiation was measured on site by scintillation counting, and burnt clay from postholes was sampled for TL dating. Because some of the clay samples were unsuitable, the

material was later supplemented by ceramics from postholes. A total of nine samples were dated. The beta and gamma dose rates and alpha dose rates from inherent uranium in the feldspar grains are listed in Table 8. The ratios of wet and dry sample weights are also given. Dating results are given in Table 9. The alpha dose contribution is unusually high, especially for the ceramic samples.

Table 8. Alpha, beta and gamma dose rates for ceramics and burnt clay from Bellingegård near Køge. The wet-and-dry weight ratios are also given.

Risø TL no.	Material	Wet/dry	Beta (mGy/a)	Gamma (mGy/a)	Alpha (mGy/a)
R-832201	Clay	-	2.38	1.03	0.17
R-832204	"	-	1.93	1.01	0.15
R-832206	"	1.33	2.64	1.03	0.16
R-832207	"	1.26	2.59	1.03	0.09
R-832208	"	1.32	2.60	1.03	0.09
R-842201	Ceramics	1.20	4.00	1.03	0.48
R-842202	"	1.08	3.55	1.01	0.45
R-842203	"	1.09	3.76	1.05	0.19
R-842204	"	1.14	4.06	1.05	0.47

On the whole, the TL dates agree well with expected ages, and the results for the ceramics are especially very consistent. However, in the cases where results from ceramics and burnt clay can be compared, there is some disagreement. Thus, for houses II and VI the TL ages for clay are significantly older than those for ceramics, whereas the results for house IV are identical. It is unclear whether the heating of the clay in connection with house burning could have been insufficient to remove all the geological TL. Some clay samples were discarded because it was obvious from the plateau test that the heating had been insufficient.

Table 9. TL dates for ceramics and burnt clay from Bellingegård near Køge.

Risø TL no.	Material	House no.	TL date	Fading 4 weeks
R-832201	Clay	II, 8	260 AD ± 100 a	1.03
R-832204	"	IV, 237	500 AD ± 100 a	0.93
R-832206	"	VI, 93	130 AD ± 120 a	0.98
R-832207	"	VIII, 3	380 AD ± 100 a	0.95
R-832208	"	VIII, 36	300 AD ± 100 a	0.91
R-842201	Ceramics	II, 35	540 AD ± 100 a	0.97
R-842202	"	IV, 164	530 AD ± 100 a	0.96
R-842203	"	VI, 72	570 AD ± 100 a	1.02
R-842204	"	VI, 195	520 AD ± 100 a	1.00

5. Stødstrup Mark, Falster

An Iron Age settlement was excavated in 1983 by Lolland-Falster Stiftsmuseum, Maribo, under the direction of Karen Løkkegaard Poulsen and Chr. Adamsen (Poulsen 1985). Seven Longhouses were registered as well as a number of barns and smaller houses. The houses made up at least three farms with partly preserved surrounding fences. Several pits were also found. The expected age of the settlement was 200-700 AD based upon the types and sizes of the houses as well as the layout of the site. However, the majority of datable finds from pits were from Late Pre-Roman on Early Roman Iron Age (ca. 200 BC - 200 AD). The finds included a few sherds from Late Bronze Age.

The environmental radiation was measured by scintillation counting during the excavation. The samples submitted for dating included four burnt stones and three small samples of burnt clay; They were all from pits because the postholes contained insuf-

ficient material. Alpha (from inherent U), beta and gamma dose rates are listed in Table 10, and TL dating results are given in Table 11.

Table 10. Alpha (inherent U), beta and gamma dose rates for samples of burnt stones and burnt clay from Stødstrup Mark, Falster.

Risø TL no.	Material	Beta (mGy/a)	Gamma (mGy/a)	Alpha (mGy/a)
R-832701	Stone	3.99	1.00	0.04
R-832703	"	3.52	1.05	0.14
R-832704	"	4.94	1.05	0.22
R-832706	"	5.94	1.00	0.19
R-832707	Clay	2.64	1.07	0.12
R-832708	"	2.98	1.07	0.12
R-842701	"	2.24	1.05	-[1]

[1] TL dating based on quartz.

The results are not entirely satisfactory. The results for stones show a larger scatter than usual, and those for the clay samples are uncertain because of the small sample sizes, 68, 43 and 27 g for R-832707, R-830708 and R-842701, respectively, as compared with our normal requirement of 200 g. The TL ages span a wider time range than expected, but are reasonable because the place could easily have been occupied in the periods indicated. However, they are not particularly helpful for estimating the time of the primary settlement under investigation, supposed to be around 500 AD.

Table 11. TL dates for burnt stones and burnt clay from Stødstrup Mark, Falster.

Risø TL no.	Material	Pit no.	TL age(a)	TL date	Fading 4 weeks
R-832701	Stone	41	1331		0.90
R-832703	"	"	1084	780AD±100a	0.93
R-832704	"	123	2249		0.87
R-832706	"	"	2628	450BC±200a	0.96
R-832707	Clay	45	1447	540AD±100a	0.94
R-832708	"	66	2569	590BC±200a	0.96
R-842701	"	800a[1]	1702	280AD±150a	- [2]

[1] "Østlige gruber a"

[2] TL dating based on quartz

6. Thorshøjgård, Torslunde near Roskilde

During excavation in 1983 undertaken by Eliza Fonnesbech-Sandberg (Fonnesbech-Sandberg 1984) and directed by Peter Vemming a house of an unfamiliar type was encountered. The house was characterised by having a very short distance between the two rows of roof-carrying posts in the middle. Ceramics found in post-holes were coarse and could give only a rough age indication to Younger Bronze Age or Older Iron Age. Typical Younger Bronze Age ceramics were found in one pit while another yielded fragments of a rotating mill (introduced around AD 200). Later, similar houses have been excavated in other areas of Zealand (Fonnesbech-Sandberg 1984), and the house in question may be compared with those found at Bellingegård near Køge (see page 15).

The environmental radiation was measured by scintillation counting during the excavation, and two ceramic samples (125 and 90 g) were received for dating. One turned out to be unsuitable, and

the other (R-833903) gave the TL date listed in Table 12. The alpha (inherent U), beta and gamma dose rates for this sample were: 0.11, 3.74 and 1,20 mGy/a, respectively. The wet-to-dry weight ratio was 1.12. The TL date is slightly older than the period indicated by the house type, but when the uncertainty is taken into account it is consistent with the time of introduction of the rotating mill.

Table 12. TL date for a ceramic sample from Thorshøjgård.

Risø TL no.	Arch. no.	TL date	Fading 4 weeks
R-833903	152 x 32	100 AD ± 150 a	0.98

7. Skonager near Varde

The excavation, undertaken in 1982 by Esbjerg Museum and directed by Palle Siemen, comprised an Iron Age settlement estimated to be from the Younger Germanic Iron Age, 600-800 AD. TL dating of ceramics from a pit house and a pit was carried out in 1934. The pit house was dated to 800 AD and the pit to 630 AD (Mejdahl 1984).

Another pit yielded ceramics with a characteristic ornamentation unlike that known from the Germanic Iron Age, but rather indicating Bronze Age. Two samples of the ceramics were dated in 1984 and the results are given in Table 13. Alpha (inherent U), beta and gamma dose rates for the samples were: 0.15, 2.30, and 0.68 mGy/a, respectively. The wet-to-dry weight ratio was 1.11.

Table 13. TL dates for ceramic samples from Skonager.

Risø TL no.	Arch. no.	TL age(a)	TL date	Fading 4 weeks
822009	FOF	1864		0.96
822010	"	1938	70 AD ±150 a	0.83

The average TL date for the two samples was 70 AD ± 150 a, i.e. Roman or late Preroman Iron Age. A Bronze Age origin of the ceramics can thus be excluded. On the other hand, the type of ornamentation found on the ceramics appears to be unknown from the Roman or Preroman Iron Age.

8. Veldbæk near Esbjerg

The excavation was carried out in 1983 by Esbjerg Museum under the supervision of Palle Siemen and comprised a mound of burnt stones and a settlement. The mound was the first of its type found in Western Jutland, but similar mounds dating to the Late Bronze Age have been found on Zealand. The settlement was estimated to be from the Younger Germanic Age, 600-800 AD.

The environmental radiation was measured by scintillation counting during the excavation. Three samples from the mound and two from the settlement were dated in 1984. Alpha (inherent U), beta and gamma dose rates for the five samples are listed in Table 14. The TL dates for the mound are given in Table 15 and those for the settlement in Table 16.

Table 14. Alpha (inherent U), beta and gamma dose rates for samples from Veldbæk. R-832013 is ceramics, the others are burnt stones. The wet-to-dry weight ratio for R-832013 was 1.10.

Risø TL no.	Feature	Beta (mGy/a)	Gamma (mGy/a)	Alpha[1] (mGy/a)
R-832001	Mound	5.19	1.35	PK:0.11; PN:0.71
R-832003	"	4.08	1.39	0.11
R-832004	"	4.26	1.39	0.06
R-832010	Settlement	4.34	0.61	0.18
R-832013	"	3.13	0.61	0.05

1) PK is potassium, PN is sodium feldspar.

Table 15. TL dates for burnt stones from a mound at Veldbæk.

Risø TL no.	Hole no.	TL date	Fading, 4 weeks
R-832001	1	830 BC ± 200 a	0.90
R-832003	2	170 BC ± 150 a	0.84
R-932004	"	250 BC ± 150 a	0.76

Table 16. TL dates for samples from postholes in the settlement at Veldbæk.

Risø TL no.	Materials	Arch. No.	TL date	Fading 4 weeks
R-832010	Stone	House 13,TL 11	950AD± 70a	0.94
R-832013	Ceramics	House 22,TL 13	850AD±100a	0.74

Sample no. 1 from the mound (R-832001) was taken in an undisturbed part of the mound, and the dating to the Late Bronze Age is in agreement with the age of similar mounds in Zealand. Subsequent excavation of the mound revealed that the area from which the two other samples were taken had been disturbed by a later Iron Age burial. Therefore, the TL cannot be expected to give the age of the original mound. They could reflect the Iron Age burial if the stones were heated at that time.

The two TL dates for material from postholes (Table 16) are identical within the uncertainty, but the resulting date, 900 AD, is more recent than expected for the site. It should be noted that the ceramic sample, R-832013, showed an unusually large fading.

9. Hindemae near Ullerslev. East Funen. (FSM 4114)

The samples consisted of slag from an iron smelting furnace that was dug down in a pit from the Preroman Iron Age, Period III a - about 150 BC. The distribution of slag lumps in the Preroman pits surrounding the furnace suggested that the site and furnace were of the same period, in which case the latter would be the oldest furnace hitherto found in Denmark.

The site and the furnace were excavated in 1978 by Jørgen Jacobsen, Fyns Stiftsmuseum, and the environmental radiation was measured with TL dosimeters during the excavation.

TL dating was attempted on the basis of sand and clay that adhered to the slag. It turned out, however, that the material had been heated insufficiently by its contact with the hot slag, and, consequently, TL dating was not possible.

10. Jels I, Southern Jutland

The site is the first settlement found in Denmark from the so-called Hamburg Culture, expected to date from around 10000 BC on the basis of pollen analysis and C-14 dating of similar settlements in Germany.

The excavation took place in the period 1981-1983 under the direction of Jørgen Holm and Flemming Rieck, Haderslev Museum. The environmental radiation was measured by scintillation counting during the excavation and four samples of the sediment in which the archaelogical material was embedded were taken for TL dating. Later, two pieces of burnt flint were found. These were TL dated by Joan Huxtable, Oxford, and gave the following results:

12,600 BP ± 1500 a
12,800 BP ± 1500 a

in good agreement with the expected age.

A preliminary TL date of 15,400 BP ± 1500 a for the sidement was obtained in 1983 using the total bleach method (Singhvi et al. 1982). However, it has been found later that this method will overestimate the age when the sediment has a significant residual dose at the time of deposition. The four sediment samples are now being dated using the quartz-feldspar technique (Kolstrup and Mejdahl 1985; Mejdahl 1985c) which is applicable also to partially bleached sediments.

TL DATING RESULTS, SWEDEN

1. Nyköping and Södertälje

The excavations were directed by Kjell Nordeman, Riksantikvarieämbetet, Stockholm. The excavation in Nyköping, kv Borgmästaren/Folkungabron was carried out in 1981. The chronological problem to be solved was whether the settlement was Early Medieval, Pre-Urban or whether the house remains reflected the beginning of the urban settlement. The area in Södertälje, kv Silen, was excavated in 1982-3. It was close to a Late Viking Age cemetery, and the question arose: Was the settlement contemporaneous with or older than the cemetery?

In both cases the TL dating was carried out on black ware ceramics that normally belong to the period 1000-1300 AD. The environmental radiation was measured by scintillation counting during a visit in 1983. Annual alpha, beta and gamma doses are given in Table 17 and the TL dating results in Table 18. The ratio of wet-to-dry weight for the ceramics was 1.08.

Table 17. Annual alpha, beta and gamma doses (mGy/a) for ceramic samples from Nyköping and Södertälje.

Risø TL no.	Locality	Beta	Gamma	Alpha
R-841901	Södertälje	4.79	1.48	0.34
R-841902	Nyköping	4.85	1.11	0.34

Table 18. TL dates for ceramics from Nyköping and Södertälje

Risø TL no.	Locality	TL date	Fading, 4 weeks
R-841901	Södertälje	860 AD ± 80 a	1.00
R-841902	Nyköping	1210 AD ± 80 a	0.98

The TL dates agree reasonably well with expected ages, the value for Södertälje being perhaps slightly older than expected. The material from Nyköping was not quite satisfactory for dating because the ceramics had been tempered with an organic substance that was difficult to remove.

2. Fosie IV, Malmö

Fosie IV is an extensive settlement place with traces of habitation from different periods between Middle Neolithic and Viking Age. The excavation was carried out by Malmö Museum in the period 1979-1983 under the direction of Nils Björhem and Ulf Säfvestad. A total of 4000 features were excavated including a large number of pits, hearths and wells as well as traces of about 115 houses, 95 of which were longhouses with wooden post constructions (Björhem and Säfvestad 1982, 1983, 1984).

The environmental radiation was measured during a visit in 1983 and samples of burnt stones from postholes in Iron and Viking Age houses were taken for TL dating. Ten stones were dated and the results are given in Table 20. Annual alpha, beta and gamma doses are listed in Table 19.

Table 19. Annual alpha, beta and gamma doses (mGy/a) for burnt stones from Fosie, Malmö.

Risø TL no.	Beta	Gamma	Alpha
R-831801	4.45	1.10	0.42
R-831803	3.13	1.10	0.05
R-831804	4.30	1.10	0.32
R-831806	4.49	1.10	0.17
R-831807	3.62	1.10	0.05
R-831811	7.24	1.15	0.16
R-831815	1.74	1.04	0.16
R-831816	5.87	1.04	0.03
R-831819	5.83	1.00	0.10
R-831820	4.12	1.00	0.10

Table 20. TL dates for burnt stones from Fosie, Malmö.

Risø TL no.	House	Hole no.	TL date	Fading 4 weeks
R-831801	93, longhouse	3899	340BC±130a	0.92
R-831803	"	"	310BC±180a	0.95
R-831804	79, quadratic house	3445	900AD± 80a	0.89
R-831806	"	"	940AD± 80a	0.85
R-831807	84, small longhouse	3820	400BC±150a	1.00
R-831811	94, longhouse,60 m	3849	610AD±100a	0.95
R-831815	96, house	4350	890BC±200a	1.00
R-831816	"	"	1050BC±200a	1.00
R-831819	66, longhouse	3200-3208	500AD± 70a	0.95
R-831820	"	"	1150AD± 70a	0.80

The TL dates agree well with expected ages, and in the cases where two samples from the same house have been dated, the results are identical, except for longhouse 66 where there is a marked difference between the two results. The excavators explained that the assembly of stones from postholes in house 66, collected before our visit, might have included stones from a particular hole placed centrally in the west end of the house. Although this hole was similar to the other holes, it could not be explained by the construction of the house and could possibly be from a different period.

3. Söder Sallerup near Malmö

The excavation comprising a number of Iron Age settlements was carried out in 1984 by Liselotte Israelson and Jan Persson, Malmö Museum. The environmental radiation was measured by scintillation counting during the excavation, and samples of burnt stones and burnt clay were taken for dating. The stones were all from postholes while the clay came from a trough-shaped pit. Annual alpha, beta and gamma doses are listed in Table 21 and the TL dating results are given in Table 22.

Table 21. Alpha, beta and gamma dose rates (mGy/a) for samples from S. Sallerup. R-842316 is burnt clay, the others are burnt stones.

Risø TL no.	Beta	Gamma	Alpha
R-842306	5.73	1.04	0.91
R-842310	5.10	1.01	0.76
R-842311	5.60	1.01	0.40
R-842313	4.75	1.02	0.03
R-842315	5.26	1.02	0.10
R-842316	2.16	1.03	0.16

Table 22. TL dates for samples from S. Sallerup. R-842316 is burnt clay, the others are burnt stones.

Risø TL no.	Feature	Arch.no.	TL date	Fading 4 weeks
R-842306	Longhouse 16	1137	950 AD ± 60 a	0.91
R-842310	Hearth pit	1352	40 AD ± 120 a	0.91
R-842311	"	"	210 AD ± 120 a	0.94
R-842313	Longhouse, 3	879	1090 AD ± 100 a	0.75
R-842315	"	"	630 AD ± 100 a	0.84
R-842316	Trough	1366	1770 AD ± 50 a	0.92

On the whole the TL dates agree with expected ages. The two results for hearth 1352 are identical within the uncertainty, whereas the two results from longhouse 3 differ significantly. The stones from longhouse 3 were taken from a pile on the ground and it could not be excluded that the pile could have contained stones from a different phase. The trough is apparently a recent feature unconnected with the Iron Age settlements. A number of the stones collected had to be discarded because they contained red or black grains that were unsuitable for dating. We have since received supplementary material, including ceramics and burnt clay, and the dating of this is in progress.

4. Södermanland, Bronze Age mounds

In connection with a study of Bronze Age centra in Södermanland carried out by Sonja Wigren, Riksantikvarieämbetet, Stockholm (Wigren 1985) burnt stones for TL dating were collected from assemblies of mounds at three localities: Vagnhärad, Lindö and Lindholm. At Vagnhärad a central area comprising the most conspicuous mounds could be distinguished from the peripheral area

some 500 m away. The mounds were not excavated, but stones were taken at depths of 30-50 cm, and the gamma radiation was measured in the holes that remained.

A total of 26 samples representing 14 mounds were dated, but 4 results were discarded because they deviated by about 1000 years from the other results; two were younger and two older.

The results for Vagnhärad have already been described in detail (Mejdahl 1984). Annual alpha, beta and gamma doses for the samples from Lindö and Lindholm are given in Table 23. The TL dates obtained for Lindö are given in Table 24 and those for Lindholm in Table 25. Mean values for the three areas are summarized in Table 26. The dating was based exclusively on feldspars because quartz from burnt stones are usually unsuited.

Table 23. Alpha, beta and gamma dose rates (mGy/a) for burnt stones from Lindö and Lindholm.

Risø TL no.	Locality	Mound no.	Beta	Gamma	Alpha
R-834401	Lindö	4	7.59	1.61	0.20
R-834407	"	5	6.28	1.83	0.02
R-834409	"	10	7.70	1.72	0.08
R-834410	"	10	4.93	1.72	0.19
R-834411	"	11	4.87	1.80	0.37
R-834415	Lindholm	1	5.70	1.82	0.21
R-834416	"	6	6.43	1.70	0.16
R-834418	"	6	5.73	1.70	0.03
R-834419	"	6	6.60	1.70	0.61
R-834420	"	10	6.25	1.63	0.08
R-834421	"	10	5.87	1.72	0.46
R-834423	"	11	6.25	1.85	0.40
R-834425	"	11	6.16	2.00	0.48

Table 24. TL dates for burnt stones from Bronze Age mounds at Lindö, Södermanland.

Risø TL no.	Mound no.	TL age(a)	TL date	Fading 4 weeks
R-834401	4	2885	900 BC ± 180 a	0.99
R-834407	5	3013	1030 BC ± 180 a	1.00
R-834409	10	2899		0.98
R-834410	10	2715	820 BC ± 180 a	0.97
R-834411	11	2844	860 BC ± 180 a	0.96

Mean TL age 2871 a; standard deviation 107 a (= 4%)

Table 25. TL dates for burnt stones from Bronze Age mounds at Lindholm, Södermanland.

Risø TL no.	Mound no.	TL age(a)	TL date	Fading 4 weeks
R-834415	1	3166	1180 BC ± 200 a	0.98
R-834416	6	3334		0.98
R-834418	6	2801	1070 BC ± 200 a	0.97
R-834419	6	3034		1.00
R-834420	10	3036		0.98
R-834421	10	2906	990 BC ± 180 a	0.98
R-834423	11	3132		1.00
R-834425	11	3296	1230 BC ± 180 a	0.98

Mean TL age 3088 a; standard deviation 182 a (= 6%).

Table 26. Mean TL dates of burnt stones from Bronze Age mounds in Södermanland.

Locality	No. of Samples	Mean TL date
Vagnhärad, central	6	910 BC ± 40 a ± 180 a
Vagnhärad, outer	3	1250 BC ± 130 a ± 200 a
Lindö	5	890 BC ± 50 a ± 180 a
Lindholm	8	1100 BC ± 70 a ± 180 a

Note: Statistical mean errors and total errors are stated.

It can be seen that all mounds date to the same Bronze Age period, around 1000 BC. The mounds in the peripheral area at Vagnhärad appear to be older than those in the centre, but it should be stressed that the date of the outer area is based on only three samples. Vagnhärad, central and Lindö are contemporaneous whereas Lindholm appears to be slightly older. Except for Vagnhärad, outer, the dating precision is high, with statistical mean errors ranging from 40 to 70 years. This indicates that it should be possible to differentiate between Bronze Age localities having age differences as small as 100 years.

5. Vuollerim, Jokkmokk, Lapland

The excavation was directed by Ulf Westfal, University of Umeå, and comprised remnants of huts estimated to be from the Stone Age. The environmental radiation was measured during the excavation, and samples of burnt stones were taken from the bottom of the huts, from pits and from a wall of burnt stones surrounding the huts (Fig. 4). Alpha, beta and gamma dose rates for the samples are given in Table 27, and TL dates based on feldspars are listed in Table 28. Because of the large scatter of the feldspar TL dates, dates were also obtained for quartz from six of the stones, these are given in Table 29.

Table 27. Alpha (in feldspars), beta and gamma dose rates (mGy/a) for burnt stones from Vuollerim, Lapland.

Risø TL no.	Hut	Feature	Beta	Gamma	Alpha
R-840702	A	Pit, 2	3.21	1.06	0.15
R-840703	"	"	4.85	1.06	0.08
R-840705	"	Pit, 4	4.66	1.09	0.13
R-840706	"	"	5.32	1.09	0.08
R-840708	"	Wall, 941	3.67	1.04	0.23
R-840710	"	"	6.11	1.04	0.22
R-840713	Norpan 1	Pit, 1	5.13	0.98	0.11
R-840713	"	"	5.66	0.98	0.06
R-840717	B	Wall	5.83	0.99	0.21
R-840718	"	"	1.94	0.99	0.10
R-840723	C	Bottom, 1	4.91	1.22	0.04
R-840724	"	"	2.04	1.22	0.09

Table 28. TL dates for feldspars from burnt stones from Vuollerim, Lapland.

Risø TL no.	Hut	Feature	TL date	Fading 4 weeks
R-840702	A	Pit, 2	220 AD ± 200 a	0.98
R-840703	"	"	2290 BC ± 300 a	0.78
R-840705	"	Pit, 4	3080 BC ± 350 a	0.83
R-840706	"	"	2220 BC ± 300 a	0.76
R-840708	"	Wall	1500 BC ± 250 a	0.76
R-840710	"	"	4790 BC ± 400 a	0.58
R-840713	Norpan 1	Pit, 1	4500 BC ± 400 a	0.70
R-840714	"	"	1860 BC ± 250 a	0.78
R-840717	B	Wall	2440 BC ± 300 a	0.81
R-840718	"	"	4180 BC ± 400 a	0.91
R-840723	C	Bottom, 1	760 BC ± 200 a	0.83
R-840724	"	"	3460 BC ± 350 a	0.82

Table 29. TL dates for quartz from burnt stones from Vuollerim, Lapland.

Risø TL no.	Hut	Feature	TL date
R-840702	A	Pit, 2	610 AD ± 150 a
R-840703	"	"	5000 BC ± 500 a
R-840705	"	Pit, 4	6830 BC ± 600 a
R-840708	"	Wall	3900 BC ± 400 a
R-840710	"	"	4350 BC ± 400 a
R-840723	C	Bottom 1	3640 BC ± 400 a

The TL dates in Table 28 show an unusually large scatter; even results for samples from the same feature differ considerably. There can be two reasons for the scatter: either some of the feldspar dates are in error, or the huts have been inhabited in different periods and the stones reused. Because there are no natural stones in the area, all stones had to be brought in from a distance of at least some hundred metres; later inhabitants would, therefore, no doubt reuse stones whenever possible, and this could give very confusing TL dates. Regarding the dates in Table 28 as a whole, most of the results fall into two groups: Five results (R-840705, R-840710, R-840713, R-840718 and R-840724) are higher than 3000 BC and thus are in agreement with the archaeological evidence. They give an average TL date of 4000 BC with a mean statistical error of ± 320 years. Another group of four results (R-840703, R-840706, R-840714 and R-840717) give an average TL date of 2200 BC with a mean statistical error of ± 120 years. Many of the samples showed a rather large fading, and it is conceivable that our present correction procedure (storage for four weeks at room temperature) is insufficient to measure the total fading. Fading experiments with storage of samples at elevated temperatures as suggested by Templer (1985) are now being undertaken. In view of the possibility that the fading correction may be insufficient, the results in Table 28 must be regarded as preliminary.

The quartz TL dates in Table 29 are considerably older than the corresponding feldspar dates except for R-840702 and R-840710. Four dates (R-840703, R-840708, R-840710 and R-840723) are reasonably consistent with an average of 4220 BC and a statistical mean error of ± 310 years.

It is unclear at present how to interpret these different results. The general experience from the Bronze Age mounds in Södermanland and many other sites is that quartz from burnt stones gives unreliable results. The reason is presumably that quartz is more affected by the uneven heating and the complex dosimetry encountered with burnt stones. Feldspars, on the other hand, have given consistent results with few exceptions. Obviously more work is required to find out the reason for the scatter of the results.

Ulf Westfal has sent the following detailed comments concerning the archaeological investigations at Vuollerim (translated by VM):

"The dating of the settlement is based on 1) The construction of the wall, 2) Artifacts and raw material, 3) Radiocarbon analysis and 4) TL.

1. Several wall constructions of burnt stones are registered in Norrland. These have been interpreted as remnants of winter dwellings with a hollowed-out floor. The wall consisting of burnt stones and other rubbish may vary in height from 10-50 cm up to about 2 m, depending on the duration of the settlement. The rather low walls at Vuollerim would thus seem to indicate a rather short period of habitation. Common for all wall constructions is their dating to Late Atlantic Period, ca. 4500 - 3500 BC in calibrated radiocarbon values (Baudou 1977, 29-30 and 96; Rydström 1984, 76).

2. More than 90% of the nearly 1400 artefacts found are made of flaked quartz. The remaining part consists of polished slate or green stone and minimal amounts of flint and quartzite. The raw material for flaking has a similar distribution.

A large amount of quartz together with polished slate, as thonged arrowheads or knives with a notch between blade and shaft may be compared with the Finnish Suomusjärvi Culture dating to the Mesolithic or Early Neolithic periods (Baudou 1978, 8-17). The flint artefacts included five microblades in addition to a number of undatable scrapers and flakes. The microblades, together with a special type of core, point to a technique that generally dates to the Mesolithic period (Spång 1978, 114-129). The occurrence of flint as well as the other finds may be placed in an Eastern connection with import of flint from Russia from the 5th millennium BC (Huggert 1984, 70). The total lack of bifacially cut quartzites, typical for the Norrland Bronze Age, as well as the absence of thin quartzite flakes infer that dating of the Vuollerim material to a period yonger than Stone Age is less likely.

3. Radiocarbon dating. Two radiocarbon dates have been made on charcoal from hut A from which material was also taken for TL dating (Figure 4). A third C-14 date was made on charcoal from one of the about 60 pits found near the settlement. The three C-14 dates are:

   St 9647: 5555 BP ± 145 a
   St 9646: 5015 BP ± 180 a
   St 9702: 6315 BP ± 315 a

   The first two give a calibrated mean value of about 4250 BC and the third corresponds to a calibrated value of about 5250 BC.

   The radiocarbon dates may be compared with the TL dates for samples for Hut A (Tables 28 and 29). Three quartz TL dates (R-840703, R-840708 and R-840710) with a mean value of 4420 BC and five feldspar dates (R-840705, R-840710, R-840713, R-840718 and R-840724) with a mean value of 4000 BC agree well with the radiocarbon dats but most feldspar dates are considerably younger. More radiocarbon dates are forthcoming.

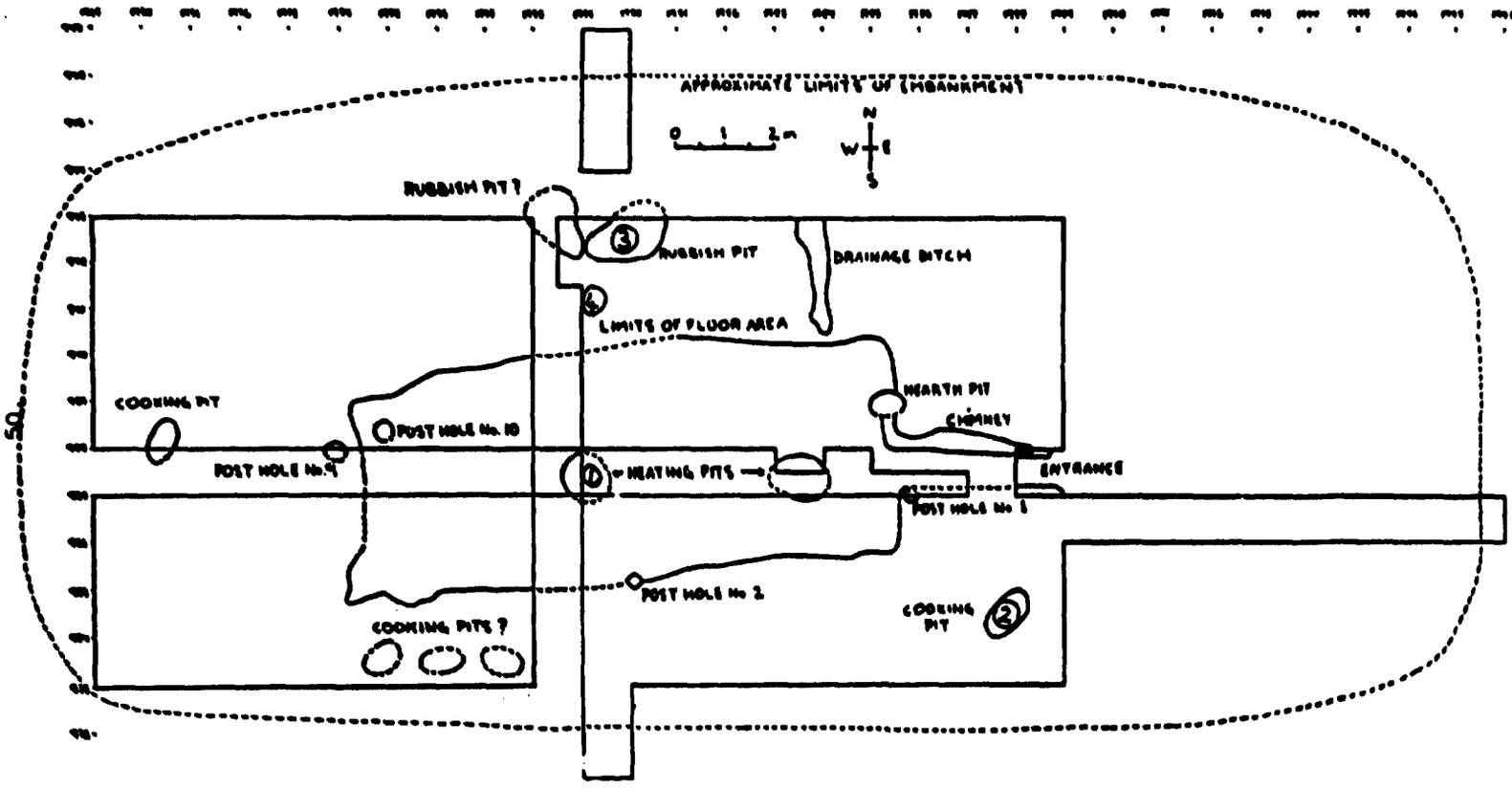

Fig. 4. Hut A excavated at Vuollerim, Norrland, Sweden. The locations of TL and C-14 samples are shown: 1) TL R-840702 and R 840703, 2) TL R-840705 and R-840706. 3) C 14 St-9648, 4) TL 840708 and R-840710. By courtesy of Ulf Westfal.

In conclusion, it can be stated that neither the wall construction nor the artefacts and raw materials nor the radiocarbon dates support the idea of repeated settlements. Repeated settlements cannot be excluded but appear to have left no other traces than those indicated by the TL dates".

6. Brottö

The excavation, directed by Bo Gräslund, Gustavianum, Uppsala, comprised a quartz quarry on an inland, Brottö, in the skerries outside Norrtälje. The quartz occurred in 20-50 cm broad veins in the rock. Based on the level of the island above the sea an age around 2000 BC was expected. Alternatively, the quarry could be from historic times, around the 17th century.

TL dating was attempted because heating had been applied in connection with the quarrying. Quartz was unsuitable for dating because of dosimetry problems and the spurious signal introduced by grinding; the dating was therefore based on feldspar that occurred together with the quartz. The environmental radiation was measured by scintillation counting during a visit in 1983. There was some difficulty in getting the scintillator completely surrounded by material in the vein. The mean value of measurements with different arrangements of blocks around the scintillator was 1.38 ± 0.11 mGy/a. The value is lower than those usually obtained for granitic rocks (see, e.g. Table 23) and may be an underestimate.

Two samples of feldspar were received for dating, but only one had been heated sufficiently. The sample was of infinite size for inherent beta, and because the uranium content was negligible (less than 0.05 ppm) the only internal source of radiation was potassium. The sample was ground to a grain size 0.1-0.3 mm and separated into potassium feldspar (11.6% K) and sodium feldspar (4.2% K). The corresponding beta dose rates are 9.63 and 3.49 mGy/a, respectively. It is possible to calculate also an infinite-matrix gamma dose rate from potassium taking into account that the two feldspar types occurred in the ratio 1.9/1;

this amounts to 2.27 mGy/a. Assuming that the sample was surrounded completely by potassium feldspar a gamma dose rate of 2.80 is obtained. These values are considerably higher than the value 1.38 mGy/a measured by scintillation counting and are maximum values because the feldspar would be diluted by quartz. The TL dates obtained for potassium feldspar using the three gamma dose-rate values are given in Table 30.

Table 30. TL dates for potassium feldspar from a quartz quarry at Brottö. Sample designation: "Under block A". (See text for explanation of the different gamma dose rates).

Risø TL no.	Beta (mGy/a)	Gamma (mGy/a)	TL date	Fading 4 weeks
R-843601	9.63	1.38	3880 BC	1.00
R-843601	9.63	2.27	3440 BC	1.00
R-843601	9.63	2.80	3210 BC	1.00

Table 30 shows that even the maximum gamma dose rate gives a TL date above 3000 BC. The use of quartz for toolmaking was well-known in the periods indicated in Table 30, but since Brottö was probably under water at that time, quarrying was not possible. The TL dates could be too old if the heating was insufficient to remove the geological TL, and this possibility cannot be excluded even though it was not apparent from the plateau test.

TL DATING RESULTS, FINLAND

1. Sulkava Ruunapäänniemi

The site was excavated by Christian Carpelan, Museiverket, Helsingfors (Carpelan 1977), and five samples of ceramics were submitted for dating by Torsten Edgren, also Museiverket Helsingfors. The ceramics were the so-called comb ware estimated to date to the period 3600-3800 BC. The environmental radiation was measured by Högne Jungner using TL dosimeters. The gamma radiation levels varied between 1.50-2.00 mGy/a and a value of 1.75 mGy/a has been assumed for the present work. The samples were small but richly tempered with coarse material. TL dating was therefore attempted, even though the sample sizes were much below our normal requirement of 200 g. Sample weights, ratios of wet-to-dry weights and beta dose rates are given in Table 31. There was not enough material for uranium determinations nor for fading measurements on individual samples. However, these measurements are now being made by combining several samples. The TL dates obtained are given in Table 32. Because of the assumptions involved, they must be regarded as preliminary. The mean value of the five dates is 3110 BC with a standard deviation of 5%. The TL dates are more recent than the expected age, indicating that fading cannot be neglected. Preliminary measurements indicate that a fading correction of 6% must be applied to the dates; this would increase the mean value to 3440 BC.

Table 31. Sample weights, wet-and-dry weight ratios (wet/dry) and beta dose rates for comb ceramics from Sulkava Ruunapääniemi.

Risø TL no.	Sample weight (g)	Wet/dry	Beta dose rate (mGy/a)
R-841301	47	1.14	3.94
R-841302	36	1.12	4.00
R-841303	35	1.12	3.53
R-841304	50	1.15	4.02
R-841305	53	1.09	2.60

Table 32. Preliminary dates[1)] for comb ceramics from Sulkava Ruunääniemi. A gamma dose rate of 1.75 mGy/a was assumed.

Risø TL no.	Arch no.	TL date
R-841301	8	2680 BC ± 300 a
R-841302	10	3350 BC ± 300 a
R-841303	247	2980 BC ± 300 a
R-841304	375	3060 BC ± 300 a
R-841305	403	2980 BC ± 300 a
Mean TL date 3010 BC ± 300 a		
Standard deviation 5%		

1) Measurement of U content and fading not yet completed.

CONCLUSION

Our techniques for TL dating of archaeological materials are now well established, and, with the results for Vuollerim as a marked and as yet unexplained exception, the TL dates obtained are usually in good agreement with other dating evidence. It is essential to make proper corrections for fading of the TL level, and the alpha dose contribution from inherent uranium in the quartz and feldspar grains must be taken into account. Improvements under study include (a) determination of alpha efficiency factors for a range of samples, (b) fading measurements of samples stored at elevated temperatures in order to accelerate the fading or localised transition in freshly irradiated samples, and (c) determination by neutron activation analysis of the concentration of thorium and other trace elements in the grains.

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45 pages + tables + illustrations

Abstract

A survey is given of archaeological samples dated in 1984 at the Nordic Laboratory for Thermoluminescence Dating. A total of 79 samples were dated, 49 of which were burnt stones. All results were corrected for fading as measured for samples stored for four weeks at room temperature. The alpha dose contribution from uranium in the quartz and feldspar grains was included assuming an alpha efficiency facotr of 0.1 for quarts and 0.2 for feldspars.

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